USAARL Report No. 2009-06

Simulator Sickness in the Flight School XXI TH-67 Flight Motion Simulators

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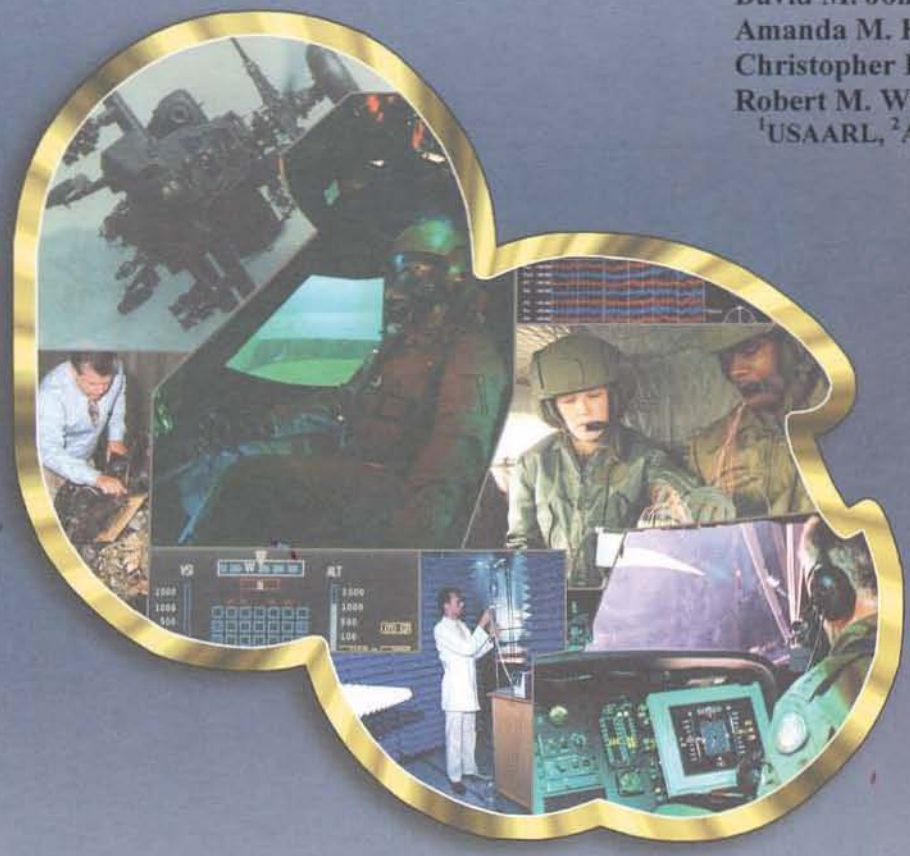

Warfighter Performance and Health Division

February 2009

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U.S. Army
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REPORT DOCUMENTATION PAGE

Form Approved
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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
18-02-2009	Final	

4. TITLE AND SUBTITLE

Simulator Sickness in the Flight School XXI TH-67 Flight Motion Simulators

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

US Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362-0577

8. PERFORMING ORGANIZATION REPORT NUMBER

USAARL 2009-06

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Army Medical Research and Materiel Command
504 Scott Street
Fort Detrick, MD 21702

10. SPONSOR/MONITOR'S ACRONYM(S)

USAMRMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In 2005, the U.S. Army debuted the TH-67 Creek flight motion simulator (FMS). Comments from the first class to use the devices indicated an unusually high number of instructor pilots (IPs) and student pilots (SPs) experienced severe simulator sickness (SS). To investigate the potential problem, a pre-study was conducted using the Simulator Sickness Questionnaire (SSQ) to collect data from three, 5-day class cycles from 73 IPs and 129 SPs. Based on an analysis of these data, along with operator comments, recommendations to reduce SS were provided. The post study was conducted one year later to test the effectiveness of the recommendations at reducing the SS symptoms. SSQ data were collected on 25 IPs and 50 SPs, over one, 3-day class cycle. After the recommendations were implemented, there was a significant reduction in SSQ scores in both IPs and SPs for three of the four SSQ subscales. Overall, IPs reported significantly greater SS than SPs across all four SSQ subscales. The implementation of the recommendations, which were based on previous findings, reduced SS in the TH-67 FMSs.

15. SUBJECT TERMS

pilots; adaptation; Simulator Sickness Questionnaire

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Loraine Parish St. Onge, PhD
UNCLAS	UNCLAS	UNCLAS	SAR	18	19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

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Prescribed by ANSI Std. Z39.18

Acknowledgments

The authors wish to thank the staff and instructors at Warrior Hall for their cooperation during this study and SFC Daniel R. Fuller for his role in data collection. Also, we wish to thank Dr. Loraine St. Onge for her extensive and constructive feedback on early drafts of this paper.

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Introduction

Since the 1950's, researchers have studied and well documented the phenomenon of simulator sickness (SS). Simulator sickness is a form of motion sickness caused by physical and/or visual motion in a simulator. Compared to motion sickness, the symptoms of SS tend to include more visual disturbances than gastrointestinal manifestations. Symptoms include dizziness, nausea, eyestrain, feelings of warmth, headache, disorientation, and fatigue. In addition, SS is known to produce aftereffects, like loss of balance and nausea, up to 6 hours (hr) after the simulator session (Johnson, 2005). The most accepted theory of simulator sickness is the sensory conflict theory proposed by Reason and Brand in 1975 (Johnson, 2005). This theory suggests that sickness results when the vestibular, visual, and proprioreceptive senses perceive motion information that conflicts with expectations based on past experience of actual flight (Crowley and Gower, 1988).

Simulator sickness has a negative impact on military aviation training, including reduced simulator use, ineffective simulator training, and compromised ground and air safety. For example, if a simulator induces SS symptoms, aviators may develop "bad habits" (e.g., limiting head movements, closing their eyes during certain maneuvers) which may carry over to actual flight and result in devastating consequences (Crowley, 1987). In accordance with Army Regulation 40-8 (Department of the Army, 2007), aircrew exhibiting symptoms of SS are restricted from actual flight for 12 hr after all symptoms completely resolve. Interestingly, aviators with high amounts of actual aircraft experience are more susceptible to SS than students with little flight time in the actual aircraft (Johnson, 2005). In this case, the amount of experience is detrimental as these aviators have developed strong expectations of actual aircraft motion and when the motion environment of the simulator conflicts with these expectations, SS often results. It should be noted that despite this initial detriment, experienced aviators should adapt to a simulator and experience less SS with increased simulator use.

The U.S. Army Aeromedical Research Laboratory (USAARL) was tasked by the U.S. Army Aviation Training Brigade to assess potential SS problems in the TH-67 Creek flight motion simulators (FMS), which are used in Initial Entry Rotary Wing (IERW) flight training at Warrior Hall, a facility near Fort Rucker, Alabama. The first IERW class to use the newly certified TH-67 FMSs appeared to have an unusually high number of both instructor pilots (IPs) and student pilots (SPs) experience sickness in the devices. The flight school Commander stressed that it was mandatory to address the SS problem quickly before the aviators lost confidence in the devices. The USAARL assembled a multidisciplinary team of subject matter experts to assess SS associated with the FMSs, provide recommendations to reduce, or preferably, eliminate these SS problems, and assess the effectiveness of the recommendations. It was hypothesized that IPs would report more SS (in terms of prevalence and severity) than SPs. An additional hypothesis was that adherence to the recommended guidelines would reduce SS.

Methods

Equipment

The TH-67 FMS is a full motion flight simulator manufactured by FlightSafety International. The simulators are used in Phase 1 of Flight School XXI for instrument and military skills training. The same TH-67 FMSs were used over the course of the entire study.

Simulator Sickness Questionnaire

The Simulator Sickness Questionnaire (SSQ) is a well validated pen-and-paper questionnaire designed to detect the prevalence and severity of 16 possible symptoms generally associated with SS including, but not limited to, fatigue, headache, eye strain, sweating, nausea, difficulty concentrating, blurred vision, vertigo, and stomach awareness (Kennedy, Lane, Berbaum, Lilienthal, 1993). Participants rate the severity of symptoms on a scale ranging from 0 (none) to 3 (severe). In addition to a total severity score, the SSQ yields a nausea, oculomotor, and disorientation subscale score, which provide diagnostic information about particular symptom categories. Stanney, Kennedy, and Drexler (1997) describe a method to categorize simulators based on mean/median values of the Total SSQ score. Total severity scores greater than 20 indicate participants are experiencing sufficient discomfort (i.e., a "problem simulator") whereas scores less than 5 indicate symptoms are negligible (See Stanney, Kennedy, and Drexler, 1997 for additional information).

Additional questions were added to the SSQ. The participants were allowed to provide subjective comments regarding their simulator experience. Data regarding contact lens/glasses use, prandial history (prior to simulator exposure), and any current SS symptoms or recent vomiting episodes were also collected.

Participants

Two hundred and two helicopter pilots (73 IPs and 129 SPs) participated in the pre-study. Data from three participants (1 IP and 2 SPs) were excluded from the analysis due to insufficient data. The mean (± standard deviation [*SD*]) age of the IPs was 51.1 ± 8.3 years (yr), and their average flight experience was 6541.7 ± 4515.8 hours (hr). Sixty-one percent of IPs reported using corrective lenses, and 57 percent (%) reported eating prior to their simulator session. The SPs' mean age was 24.8 ± 3.2 yr and their mean flight experience was 48.6 ± 194.9 hr. Only 3% of the SPs reported using corrective lenses, and 52% reported eating prior to their simulator session.

Seventy-five helicopter pilots (25 IPs and 50 SPs) participated in the post-study. Of the 25 IPs in the post-study, 17 also participated in the pre-study. Given that the objective of this study was to assess changes in SS at the same location (flight school) prior to and following the implementation of strategies to reduce SS, it was expected that some IPs would be included in both studies as the staff would remain constant over the course of the study (i.e., one year) whereas the student population would undoubtedly change. Instructor pilots who participated in

both the pre- and post-study were not matched to evaluate individual change because the data was de-identified. The mean (± *SD*) age of the IPs was 51.9 ± 8.1 yr, and their average flight experience was 7770.4 ± 5195.8 hr. Sixty percent of IPs reported using corrective lenses, and 72% reported eating prior to their simulator session. The SPs' mean age was 26.7 ± 3.8 yr and their mean flight experience was 27.6 ± 92.5 hr. Similar to the pre-study, only 6% of the SPs reported using corrective lenses, and 60% reported eating prior to their simulator session.

Procedure

For the pre-study, data was collected over three, 5-day class cycles. On the first day of data collection, each IP was assigned two SPs. For each simulator session, one student flew the simulator, while the other student observed from the rear area of the simulator cabin. After 2 hr, the students changed roles. The IP remained in the front seat during both sessions. On each day of the class cycle, the students and their IP completed the SSQ immediately after the simulator flight period. The participants did not use the same individual simulator for all 5 days of data collection; simulator assignments were based on availability. A total of 950 SSQs were completed in the pre-study and provided to USAARL as de-identified data. Inasmuch, the participants were not subject to informed consent.

Based on results of the pre-study, recommendations were made and implemented during the post-study. Procedures were similar to those in the pre-study however the class cycle was shortened from 5 days to 3 days; thus data was collected over a 3-day class cycle. Additionally, the time each student flew the simulator was reduced from 2 hr each to 1.5 hr. Finally, informed consent was obtained from each participant. The SSQ was completed at the end of the simulator session on each of the 3 days of the class cycle. Data from 225 SSQs were collected in the post-study.

Results

Descriptive results

Pre-study

In the pre-study, participants completed the SSQ across one, 5-day class cycle (i.e., five administrations). The most commonly reported symptoms overall included eyestrain, general discomfort, headache, and difficulty focusing. Regardless of severity, 72% of IPs and 91% of SPs reported at least one symptom over the course of the five sessions. As for the profile of the SSQ subscales, disorientation symptoms predominated, followed by oculomotor symptoms. The mean SSQ scores from the first and last administrations of the pre-study are presented in table 1.

Table 1.
Mean ± SE SSQ scores of first and last administrations during the pre-study.

	Nausea Scores			
	IPs		SPs	
	Pre-study	Post-study	Pre-study	Post-study
First Administration	12.28 (2.58)	7.63 (2.27)	7.77 (1.15)	15.65 (3.35)
Last Administration	27.71 (4.44)	13.74 (3.94)	12.72 (1.75)	10.68 (2.46)
	Oculomotor Scores			
	IPs		SPs	
	Pre-study	Post-study	Pre-study	Post-study
First Administration	13.19 (2.15)	8.19 (2.39)	10.11 (1.32)	13.49 (2.73)
Last Administration	27.59 (3.82)	12.73 (4.28)	14.87 (1.80)	11.52 (2.20)
	Disorientation Scores			
	IPs		SPs	
	Pre-study	Post-study	Pre-study	Post-study
First Administration	17.16 (2.87)	10.02 (2.84)	9.60 (1.67)	16.43 (4.39)
Last Administration	34.89 (5.74)	17.82 (7.52)	15.43 (2.41)	15.03 (4.21)
	Total Scores			
	IPs		SPs	
	Pre-study	Post-study	Pre-study	Post-study
First Administration	15.93 (2.64)	9.72 (2.44)	10.64 (1.39)	17.20 (3.49)
Last Administration	33.87 (4.98)	16.46 (5.40)	16.47 (2.03)	13.84 (2.90)

In order to assess the change in SS over the 5-day class cycle, differences in each SSQ subscale score and total score from the first administration to the last administration were calculated for each participant. This calculation yielded four “difference scores”; namely, nausea difference score, oculomotor difference score, disorientation difference score, and total difference score. As shown in table 1, prior to the recommendations, both IPs and SPs scores on all four SSQ scales increased from the first administration to the last administration resulting in negative difference scores. This indicates that SS symptoms worsened over the course of the five-day class cycles.

Informal subjective comments were reviewed and taken into consideration when forming recommendations. Common negative comments were related to the hover training, yawing (especially near ground level), rear seat discomfort, and visual display problems (height above terrain and blurriness/out of focus).

Recommendations

After analyzing the data from the pre-study, a number of recommendations to reduce SS were provided to the directors of Flight School XXI. The recommendations that were implemented and incorporated into the simulator training program were: simulator flights were reduced from 4 to 3 hr (1.5 hours per student); pilots were instructed to close their eyes before freeze/reset; and unusual or unnatural maneuvers were limited. The course was reduced from 5 days to 3 days since most of the hover training and ground work were removed from the program of instruction entirely. There was an effort to avoid improperly calibrated simulators (e.g., misalignment, out of focus, luminance mismatch, distortions) until repaired. And finally, emphasis was placed on stressing the importance of proper rest/health discipline, and giving instructors enough time to adapt and maintain adaptation. A list of the recommendations (including those not implemented) is located in table 2.

Table 2.
Conditions that increase the likelihood of SS and recommendations made to counteract those conditions.

Conditions contributing to SS	Recommendation to counteract SS
Session duration	2 hr daily maximum
Use of the freeze/reset command	Close eyes before freeze/reset
Unusual or unnatural maneuvers	No flying into buildings, radio towers, or air traffic
Maneuver intensity	IPs not allow students to get too far out of control
Height above terrain	If discomfort arises, limit hover/autorotation training
Degree of aircraft control	If discomfort arises, remove SP from back seat
Head movements	Limit head movements
Wide field of view visual displays	If discomfort arises, turn off side screens
Off-axis viewing; out of design eye point or viewing region	If discomfort arises, get student out of back seat
Optical distortion caused by misaligned or poorly calibrated optics	If visual display not “right” do not use simulator until fixed
Fatigue and sleep loss	Maintain health/rest at individual level

Post-study

One year following the pre-study, after the recommendations were implemented, the post study was conducted. The IPs and SPs completed the SSQ across one 3-day class cycle (i.e., three administrations). In the post study, the most commonly reported symptoms included eyestrain, general discomfort, nausea, and burping. With regard to frequency data, 64% of IPs and 90% of SPs reported at least one symptom, regardless of severity, over the course of the 3 days. The profile of the subscales was the same as that of the pre-study, with disorientation

symptoms predominating, followed by oculomotor symptoms. The mean SSQ scores from the first and last administrations are presented in table 1.

Differences scores were calculated as previously described. Table 1 shows that in the post study, IPs scores for all four SSQ scores increased from the first administration to the last, resulting in negative difference scores. Although SS was increasing over the class cycle, it was not to the same extent as in the pre-test. In other words, the absolute values of the difference scores were larger in the pre-study than in the post study. For the SPs, however, scores for all four SSQ scales decreased from the first administration to the last, resulting in positive difference scores. This indicates that SS symptoms improved over the course of the 3-day class cycle.

Parametric results

To determine the effectiveness of the recommendations in reducing SS, a 2 (IP/SP) x 2 (pre-study/post-study) between-subjects Multivariate Analysis of Variance (MANOVA) was used. The two independent variables were experience (IP or SP) and recommendations for SS reduction (pre-study vs. post-study) and the four dependent variables were the differences in nausea scores, oculomotor scores, disorientation scores, and total scores of the SSQ. Of particular interest was the comparison of the difference scores from the pre-study to those of the post study. The MANOVA showed that there was a significant main effect of experience, $F(4, 270) = 3.055$, $p = .017$, and a significant main effect of the recommendations, $F(4, 270) = 2.628$, $p = .035$. There were no significant interactions. Levene's test of equality of error variance showed that this assumption was violated. To account for this, the data were subsequently analyzed using independent *t*-tests (equal variances not assumed) and a Bonferroni correction was applied to reduce the risk of a Type 1 error ($p = 0.05/6 = 0.0083$).

Nausea scores

Independent samples *t*-tests showed that there was a significant main effect of experience on nausea difference scores, $t(275) = -3.50$, $p = 0.001$, such that IPs had significantly larger (more negative) difference scores, and thus experience more SS than SPs. There was also a main effect of the recommendations on nausea difference scores, $t(275) = -3.03$, $p = 0.003$, such that difference scores were more negative in the pre-study, thus indicating that nausea SS symptoms were more severe over the class cycle in the pre-study than in the post-study.

Oculomotor scores

Independent samples *t*-tests showed that there was a significant main effect of experience on oculomotor difference scores, $t(275) = -3.27$, $p = 0.001$, such that difference scores were greater (more negative) for IPs than SPs. A significant main effect of the recommendations on oculomotor difference scores also emerged, $t(275) = -2.68$, $p = 0.008$, such that difference scores were more negative in the pre-study than in the post-study. In other words, oculomotor SS symptoms were more severe over the class cycle in the pre-study than in the post-study.

Disorientation scores

Independent samples *t*-tests showed that there was a significant main effect of experience, $t(275) = -2.80$, $p = 0.005$, such that IPs had greater (more negative) difference scores than SPs. A marginally significant effect of the recommendations emerged, $t(275) = -1.93$, $p = 0.055$, on disorientation difference scores.

Total scores

Independent samples *t*-tests showed that there were significant main effects of experience on total difference scores, $t(275) = -3.53$, $p < 0.001$, and of the recommendations on total difference scores, $t(275) = -2.80$, $p = 0.006$. The direction of those effects was the same as for the other difference scores reported. In terms of overall SS, symptoms were more severe over the class cycle in the pre-study than in the post-study, indicating the recommendations were effective at reducing SS.

Discussion

According to Stanney, Kennedy, and Drexler (1997), simulators producing mean total SSQ scores greater than 15 are a concern, and scores greater than 20 indicate a "problem simulator". As shown in table 1, the TH-67 simulators could be classified as problem simulators in the pre-study. In addition, the profile of the three subscales indicated that disorientation symptoms predominated in both the pre- and post-study, which is atypical of SS, in which oculomotor symptoms are most frequently observed. High disorientation scores are correlated to postural instability following simulator sessions (Kennedy, Berbaum, and Lilienthal, 1997), which raises concerns regarding ground safety (e.g., exiting the simulator, driving home from the simulator session, and even flying aircraft).

Rotary wing aircraft are known to cause higher rates of simulator sickness compared to fixed wing aircraft (Johnson, 2005). Crowley (1987) reported a 40% SS rate in an AH-1 Cobra simulator, while Gower et al., (1987) found a 44% SS rate in their analysis of the AH-64 Apache simulator. Other reviews of rotary wing flight simulators found the occurrence of simulator sickness ranged from 13 to 70% (Wright, 1995). The occurrence of SS for both the pre and post studies (64 to 91%) are high compared to other frequency rates published in the literature for military flight simulators. There are several possible explanations or factors that may have contributed to the high frequency rate. For example, the logistics of Flight School XXI require an SP to be in the back of the FMS while another SP is in control. Degree of control is an important factor influencing SS, as sickness decreases as the amount of control increases (Johnson, 2005). Also, this study included several IPs with many thousands of hours of flight experience, another factor well known to increase susceptibly to SS (Johnson, 2005). Lastly, data was not collected regarding the prior histories of motion/simulator sickness in the participants.

Consistent with previous SS literature, in both the pre- and post-studies, IPs reported significantly higher SSQ scores than the SPs for all four SSQ subscale scores. While this finding

was expected on the first day of simulator flight, the IPs showed an increase in SS symptoms over the 5-day course in the pre-study and the 3-day course in the post-study which was unexpected. Despite the role flight experience plays in SS, IPs would be expected to adapt to a simulator over time. There are a number of factors which may have contributed to this unexpected finding such as lack of control over previous day activities (simulator versus actual flight) and variability in instructor schedules. This is, of course, speculation and additional research will need to further identify the root cause of the absence of adaptation in the IPs.

According to Johnson (2005), the best current solution to SS is adaptation (i.e., developing a tolerance to the stimuli that produce sickness). Tsang and Vidulich (2003) report pilots who are frequently exposed to extreme maneuvers show reduced vestibular response in clinical rotary tests. The authors also report that when pilots do not fly for a few weeks, their vestibular responses return to normal. There are also individual differences with regard to adaptation and habituation; approximately 5% of the population will continue to experience symptoms even after very repetitive exposures to provocative motion. Adaptation will normally occur in approximately six sessions; for optimal adaptation, these sessions should be 2 to 5 days apart. Upon adaptation, sickness often is eliminated or greatly reduced. This study revealed evidence of adaptation in the nausea SSQ score in the post-study. Perhaps, for the post-study, the 3-day class cycle was not long enough to adapt significantly to the other symptoms of SS. However, it is important to note that the implemented recommendations were in fact improving adaptation for both IPs and SPs as evidenced by the significant changes in difference scores.

Limitations

Although every effort was made to ensure the recommendations provided were implemented, factors such as costs and practicality limited the implementation of some recommendations. Additionally, some behaviors continued that were not recommended, such as positioning the SP in the back seat when not flying. While it may never be possible to completely ameliorate SS in the Flight School XXI TH-67 FMS, the recommendations that were implemented did reduce symptoms of SS and should be practiced in the future.

As previously mentioned, SS is known to produce aftereffects, like loss of balance and nausea, even 6 hr after the simulator session (Johnson, 2005). Although rare, these aftereffects can compromise air and ground safety. In both the pre- and post-studies, pilots were only asked to complete an SSQ immediately after their simulator session. Therefore, we cannot make any claims regarding the rate of aftereffects for the present study. Future studies should strive to collected SS data well after the simulator session.

A number of factors need to be taken into consideration in future studies to improve the interpretability of SS data. For instance, data was unavailable as to which TH-67 FMS each individual participant used each day. This lack of consistency in simulator use introduces a potential confound to the study thus limiting the precision of conclusions. Future studies should track simulator use/assignment to determine if SS is more prevalent and/or severe in a particular FMS. Finally, in the pre-study, data was collected over three class cycles whereas data was only collected over one class cycle in the post study. Thus, the violation of the homogeneity of

variance assumption was potentially due to the unequal sample sizes of the pre- and post-studies. Future studies should aim to ensure equal sample sizes when comparing group differences.

Conclusion

Flight simulators are a safe and cost effective alternative to actual flight and are an invaluable tool for training SPs. However, as the Army introduces advances in simulator technology, it cannot afford to ignore the lessons of the past. These studies provide evidence that adherence to well documented simulator practices within the task, simulator, and individual domains can reduce the prevalence and/or severity of SS in emerging flight simulation systems. These practices should be considered first among the investigators myriad of tools called upon during his/her initial approach to ameliorating any symptoms manifest in this rapidly expanding field of training and technology.

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